Innovative ground treatment solution for rail bridge renewal

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ABSTRACT

The first application of jet grouting for an Australian transportation authority was recently carried out in New South Wales. This paper describes the design and installation of a jet grouted deep foundation system to support a rail bridge on the Main North line, just north of Lisarow, NSW as part of a bridge renewal. The adopted method of jet grouting is a replacement/mixing technology that uses a high pressure jet to erode and hydraulically excavate soils, to form a grouted soil mass.

The project was completed on schedule during limited track possession time, under low headroom conditions. The specification requirements, design, installation, monitoring and post-construction performance of the successful footing system are outlined in this paper.

1. INTRODUCTION

A railway bridge built in 1911 on one of Australia's major railways has been given a new life through the first application of jet grouting to support a rail bridge in Australia. Jet grouting technology is growing in popularity in various parts of the world due to its cost-effectiveness and proven performance, but to the author's knowledge, it has never before been used by an Australian transportation authority to support a bridge.

The bridge spans about 19m across Cut Rock Creek, 90 km north of Sydney between Gosford and Wyong. It was originally built of masonry piers on timber piled foundations, with about 2.3 m clearance between the steel superstructure and the creek. Originally designed for steam-powered trains, the aging foundations needed to be upgraded to support today's heavier rail traffic and to reduce ongoing maintenance costs. For the Rail Corporation of New South Wales (RailCorp), the choice was between shifting the existing structure to new piers at a higher cost and significant disruption to train traffic or finding a way to strengthen the existing foundations to support a new bridge.

The project presented the authors with the challenge of how to support a rail bridge on soils where the estimated settlement was unacceptable whilst minimising disruption to rail traffic. After evaluating a number of options, PB and RailCorp concluded that ground treatment would be the preferred solution. A load transfer slab and culverts support the bridge loads applied to the 23 metre deep foundations.

2. SITE DESCRIPTION

The site is located at Cut Rock Creek, just north of Lisarow, which is 88.815 km north of Sydney on the Main North Railway Line (see Figure 1). The previous bridge structure was a two span, transom topped bridge supported on a brick pier and abutments (see Figure 2). The creek bed reduced level is 19.7 m AHD under the bridge at the lowest level, and the 100-year level is 22.7 m AHD.

2.1 Site investigations

Site investigation fieldwork included borehole drilling and sampling, cone penetration testing (CPT), and pressuremeter testing. The boreholes were drilled with truck-mounted drilling rigs using open hole augering and concrete coring techniques, and air track drilling. Standard penetration testing (SPT) and U50 (50mm) tube sampling were carried out. The CPT probes were performed using an electric 100 kN truck-mounted rig, without pore pressure measurement.

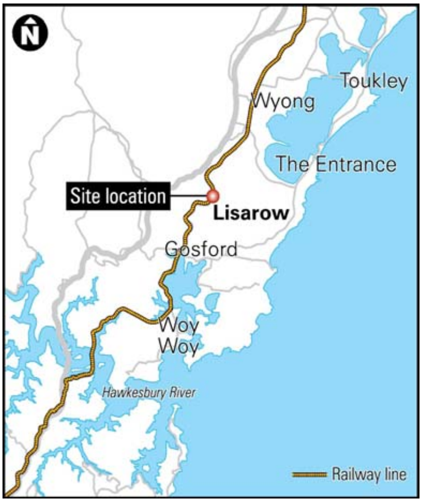

Figure 1: Site location plan

Figure 2: Previous bridge showing jet grout installation

2.2 Subsurface Conditions

Subsurface conditions at the site comprise compressible, estuarine and alluvial soils to depths of about 17 m to 20 m, overlying siltstone. The ground conditions comprise, from youngest to oldest:

- 3 m to 5 m of loose silty sand with a very low limit pressure (Pl), typically in the range of 100 kPa to 200 kPa
- soft to stiff clay/silty clay from RL 16.5 m to 8.5 m with cone resistance between 0.5 MPa and 2 MPa and limit pressures of 600 kPa. The elastic modulus ranged from 13 MPa to 20 MPa
- interbedded thin layers (1 m thick or less) of hard clay/dense sand or gravel from RL 12 to 8.5 m
- siltstone at a depth of about 17 m to 20 m.

Figure 3 shows the inferred ground profile in the creek bed.

3. FOUNDATION SELECTION

RailCorp's preferred option for replacement of the existing bridge was a concrete box culvert. However, due to poor ground conditions, the site offered a very low bearing capacity and the prospect of unacceptable settlement, hence the use of conventional culvert foundations was not possible without piling or ground treatment.

Without ground treatment or deep foundations (piles), the bridge was predicted to settle up to 200 mm under a serviceability load of 100 kPa. Piles were not considered suitable due to the existence of adjacent, vibration and settlement-sensitive utilities, including fibre-optic cables, rail communications, a water main and limited clearance of 2.3m beneath the existing bridge.

PB provided a specification, reference design, construction surveillance and certification for the works. Tender documents were targeted at achieving the required performance, based on adopting a ground treatment method suited to the difficult site conditions which complied with design criteria.

3.1 Options considered

Since a conventional deep foundation system was not considered practical, specialist ground treatment contractors were selected to tender for the works on a design and construct basis, based

C:\Documents and Settings\Matt\Local Settings\Temporary Internet Files\OLK50\0012HEWITT-SPAULDING Lisarow Rail Bridge rev FINAL (2).doc on tender documents prepared by RailCorp and PB. Six tenders were received from three tenderers. Details of the proposed methods submitted by the tenderers are summarised in Table 1.

Following a rigorous tender evaluation process, Austress Menard was selected from a group of three competitors and awarded the performance criteria based, design-construct ground treatment contract using jet grouting. Advantages of the jet grouting scheme were as follows:

- all soil types were groutable
- ability to work around buried active utilities and obstructions (e.g. rail line)
- can be performed in limited workspace/headroom
- specific in situ replacement possible
- treatment to specific locations
- designable strengths and stiffness
- only inert components
- no harmful vibrations
- maintenance-free
- faster than alternative methods, and
- design addressed performance criteria.

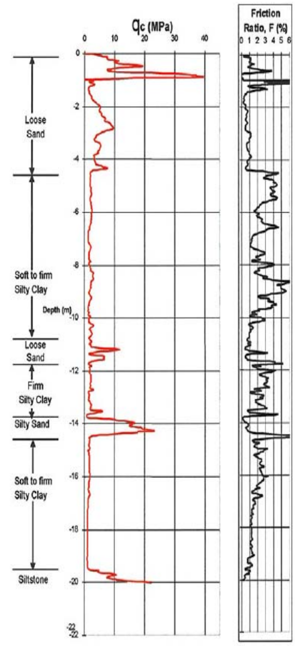

Figure 3: Inferred ground profile and typical CPT data

Table 1: Ground treatment methods submitted by tenderers

Method	Schedule	Description and tender details	Relative cost	Comments
Jet grouting	4-5 weeks	18, 1100mm diameter jet grout columns to about 20 m depth. Replacement ratio 6% on 3.3 m x 3.6 m grid.	1.0 -1.2	Jet grout columns to rock using a mono-fluid system. Predicted settlement complies with design criteria.
Compaction (displacement) grouting	10 weeks	Compaction or displacement grouting is a technique of injecting very low slump grout under high pressure to densify or controllably displace mostly granular soils. Designed to take foundation loads to the surface of the stiffer silty clay at about 6m depth.	1.1 -1.4	Addresses substantial expected settlement in top 6 m only. About 25-30 mm settlement predicted after treatment, compared to 160 –200 mm without.
Minipiles	-	Grout injected minipiles – 150 mm diameter to 20 m depth at 1m centres. Capable of being installed in low headroom conditions to the underlying siltstone.	2.0 -2.3	Option rejected on the basis of the likely extended installation time and cost.

4. JET GROUTING DESIGN

Jet grouting is a partial replacement/mixing technology that uses a tool equipped with one or more high pressure jets to erode and hydraulically excavate soils, while mixing cement grout with the insitu soils, creating soil-cement columns or soil-cement panels (Bruce 2005). The soil-cement columns are designed to carry loads to the siltstone, thereby mitigating the risk of settlement in the compressible soils (see Figure 4). Therefore jet grouting reworks the soils in three distinct physical processes:

- breaking down the soil formation using a very high-velocity (energy) jet
- removing spoil to the surface via the return flow, and
- introducing and incorporating a binder in the form of a grout.

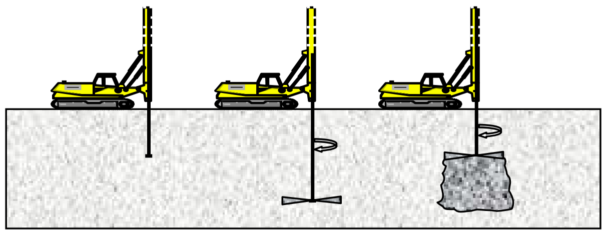

Figure 4: Schematic of jet grouting construction procedure.

4.1 Design criteria

Performance criteria for evaluating the method of preferred treatment, including compliance with RailCorp track maintenance specification and British Standard BS EN 12716:2001, "Execution of special geotechnical works – Jet grouting", were:

- immediate settlement/heave of less than 20 mm
- residual settlement limited to a maximum of 50 mm over a 10-year maintenance period
- maximum settlement of 15 mm over any 12 month period following construction completion
- differential settlement (change in grade) of $\leq$ 0.3% longitudinally, and <0.1% transversely
- compliance with RailCorp track maintenance limits.

4.2 Design and settlement

Design of the jet column network adopted a calculation that took into account both stress and deformation. This calculation included the behaviour of the soil, the jet column and ground and ground/ grout interaction. In particular, computer programs using simple failure analysis, which are commonly used for routine geotechnical calculations, are not appropriate.

The design process involved determining for a given diameter, the centre-to-centre spacing and anchorage (bond) length of the column, the distribution of stresses between the soil and columns and the corresponding settlement of the structure. The calculation was based on the French Laboratoire Central des Ponts et Chaussees (LCPC) design method for a mixed shallow/deep foundation (Combarieu, 1990). This involved the use of:

- the Combarieu (LCPC) method to evaluate the negative skin friction and neutral point effect (negative skin friction limited to the upper part of the column length)
- the Frank and Zhao (1982) method to evaluate the settlement of the columns in the surrounding soil
- Hooke's law for the column material (elastic behaviour).

Checks were made to establish whether the calculated valued of the stresses were acceptable for the slab-on-grade and were compatible with the jet column material, and if the settlements were acceptable for the structures. An iterative calculation was then conducted until an equal deflection of the soil and of the columns was obtained. Details are given in Hewitt & Spaulding (2006).

Due to the layout of the columns (see Table 1), and the transfer of load through the culvert walls, the area of soil and load per column varied across the area to be treated. The total predicted settlement at the top of the piles was less than 20mm, with a peak service stress in the column of 2.3 MPa.

5. CONSTRUCTION

Following construction of a coffer dam, to protect the site against inundation, and a working platform, the soil improvement works were performed using a mini jet grouting rig with a hydraulic 3.0 m height mast to execute the works from underneath the bridge apron (see Figure 2). A total of 18, 1100 mm-diameter columns were constructed between 16 June and 15 July 2005, to a maximum depth of 27.5 m.

The cement used was a low shrinkage portland cement. The resulting composition of the soil-cement mix related to the jetting parameters (flow and grout lifting speed) and to the degree of displacement of soil by grout, in order to obtain the target strength of 4.5 MPa specified for the soil-cement mix columns. The grout dosage typically ranged between a water/cement ratio of 0.8 and 1.0.

The jet grouting parameters as well as the work sequence had to be adjusted almost daily to minimise any impact on the live railway structure, particularly in terms of movement, especially ground heave. Changes in work method involved pre-cutting from top-down or bottom-up using water or cement grout and at medium to high pressure (25 MPa to 45 MPa typically), with a particular emphasis on monitoring the spoil returns to prevent any pressure build-up in the ground. Loss of spoil meant interrupting the column or the pre-cut and repeating the pre-cutting of the column, top down.

Management of the spoil generated by pre-cutting and jet grouting sought to prevent any contamination of the groundwater. Temporary platforms on each side of the bridge central pier were used to divert the flow away from the platform. The spoil was then funnelled away from the working area using a system of clay bunding and a 4 inch pump, before dredging into a stockpile area.

6. OBSERVATIONS, MONITORING AND TESTING

6.1 Effects on adjacent ground

Effects on adjacent structures were closely monitored during the jet column installation, because of risk associated with the presence of soft clay combined with the use of high-flow injection techniques. At one stage, the centre pier was lifted 28 mm which disrupted train running. As a result of the monitoring, the jet grouting column installation was progressively refined using an observational approach, until "zero movement" was observed at the monitoring points.

6.2 Instrumentation

An instrumentation and monitoring program was specified to monitor ground and structure movement in the vicinity of the works to measure:

- ground movements
- angular distortion of the track
- settlement of structures
- settlement of utilities

Monitoring included settlement indicators, inclinometers and rail track tilt measurements.

6.3 Column testing

Testing of the soil-cement was essential, because accurate design and prediction methods for column properties and load-deformation characteristics are currently limited. Before the final columns were constructed, a sacrificial demonstration column was installed. Strengths of between 5 MPa and 8 MPa (UCS) were obtained from soilcrete samples in completed jet columns.

7. PERFORMANCE

Monitored instruments confirmed that soil-cement columns were effectively supporting the bridge. The data showed:

- less than 5 mm horizontal movement of the brick pier and abutment during jet grout installation
- less than 6mm settlement following construction completion
- movement at the bridge (six points): controlled heave of between 3 mm and 44 mm
- relative movement of pier/abutments (rotation): less than 5 mm (precision of instrument)
- heave at rail level: less than 5 mm measured on a weekly basis between 27 June and 12 July 2005.

The bridge remained open during the soil improvement works and new section was opened to traffic in November 2005

8. CONCLUSION

Although jet grouted foundations have a history of being relatively expensive, the total cost of the jet grouting was significantly less than the cost of constructing new bridge foundations and piers, and less disruptive to train operations and adjacent utilities. Other benefits included that, unlike other types of piles installed by pile-driving techniques, jet grouting did not endanger the existing bridge structure through vibration, nor did it affect nearby fibre-optic cable installations. It could also be done in the tight workspace and low headroom conditions present beneath the underbridge.

The rail bridge renewal was done with minimal disruption to train traffic and minimal environmental impact, demonstrating the viability of this technology and its suitability as a solution for this situation. Settlement observations indicated that there were no noticeable post-construction effects on adjacent structures. Successful construction and performance of the jet grouted deep foundation, is proof of the success of the adopted solution.

9. ACKNOWLEDGEMENTS

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